AN OPTICAL SWITCHING APPARATUS AND METHOD FOR FABRICATING

Background of the Invention

1. Field of the Invention

This invention is related to an optical switching apparatus used in an optical network for voice and data communications. More particularly, embodiments of the present invention provide for an optical switching device and method for fabricating, forming or producing an optical cross-connect switching device.

2. Description of the Related Art

Strong growth of optical networks for voice and data communication results in huge demand for high data rate information transfer capabilities. To enable such transfer capabilities, dense wavelength division multiplexing (DWDM) technology has been developed which allows transfer of multiple wavelength over the same fiber leading to data transfer rates up to 40-100 Gb/s. High speed switching and routing devices comprise the core elements of the optical networks and allow dynamic control of the data traveling over the optical network. Furthermore, high data transmission rates impose strong requirements on the functionality of the switching devices.

Optical cross-connect space division switches based on optic-electro (OE) deflection of the light beam have great potential for future implementation in high speed optical networks. One of the basic concerns is the switching time and a capability of handling a great number of input and output channels, e.g., up to 4000x4000 by the year 2003, as well as reliability and cost factors. Existing optical switching devices which employ signal conversion from optical into electrical and back into optical do not satisfy those requirements. Having very low switching times switching matrixes can be designed to connect very large number of input and output (I/O) ports. Such switches may be built from an assembly of simple digital optical switches where each can redirect one input signal into two possible output ports. However, optical cross-connect switching elements are more useful for large-scale implementations. These devices require

large-scale monolithic switch arrays to perform switching functions. Although, the main principle of the optical cross connect switching based on the light beam deflection is well known, a robust, reliable, low cost and extendable integration process for such type of switching device is not available.

Currently, the main optical switching products on the market (e.g. Lucent's Lambda-router) are based on MEONIS technology, which employs rotating micro-mirrors to deflect light. However, these optical switching devices are not very reliable due to many moving parts, and also the switching time is limited by the mechanics of the mirrors. It is desirable to improve the reliability of the many moving parts of the optical switching devices and to overcome the limitation of the switching time in these devices due to the mechanics of the micro-mirrors.

There are several other optical switching technologies which are still not well represented in the market due to various technological and economic difficulties. Such optical switching technologies include by way of example only: the bubble switch from Agilent Technologies Inc., switches based on liquid crystals, and thermo-optic and electro-optic (EO) effects, etc. Most of these devices are still in the R&D stage. Some of those technologies including EO switches may be applicable for high speed, low cost, high reliability, and high I/O port count products. However, as of today no proven technology has been developed which can satisfy the above-mentioned requirements.

Therefore, what is needed and what has been invented is an improved optical switching device and method for fabricating the improved optical switching device. What is further needed and what has been invented is an integration process which allows for fabrication of a non-blocking optical cross-connecting switching matrix possessing a large number of input and output channels.

Summary of the Invention

Embodiments of the present invention provide a hybrid integration process for fabrication of an optical cross-connect switching device. The switching element is based on the deflection of light beam in electro-optic materials by applying electric field across electrodes of an appropriate configuration, e.g. prisms, gratings, etc. The integration process includes fabrication of a substrate, e.g. silicon substrate, with 2D (two-dimensional) imaging optics from polymeric materials or silica, fabrication of the light deflecting element, and assembly of the deflecting element on the substrate with imaging optics. The fabrication of the light deflecting element includes fabrication of a LN (lithium niobate) block. The LN block assembled in an optical switching apparatus includes a two-dimensional waveguide formed on a surface of the LN block and an electrode on a surface of the LN block.

Embodiments of the present invention further provide a method for producing an optical substrate assembly comprising providing a substrate; disposing a first cladding layer on the substrate; forming a first recess in the first cladding layer; disposing a plurality of first deflector electrode assemblies in the first recess; disposing a core layer on the first cladding layer and over the first electrode assemblies; and forming microlenses in the core layer to produce an optical substrate assembly. The foregoing method additionally comprises forming an alignment frame assembly in the core layer. Forming of the alignment frame assembly includes forming a plurality of spaced corner assemblies and etching openings in the first cladding layer down to the substrate. The openings may border on the first recess. The foregoing method additionally comprises depositing a protective layer in the first recess.

Embodiments of the present invention also further provide a method for producing an optical switching apparatus comprising providing a substrate; disposing a first cladding layer on the substrate; disposing a plurality of first deflector electrode assemblies on the first cladding layer; disposing a core layer on the first cladding layer and over the first electrode assemblies; forming microlenses in the core layer to produce an optical substrate assembly; forming an alignment frame assembly in the core layer; and engaging the alignment frame assembly with an optical switching device. Forming the optical switching device comprises providing an optical switching substrate; diffusing an element into the optical switching substrate to produce a waveguide layer in the optical switching substrate; and disposing a plurality of second deflector electrode assemblies on the optical switching substrate. The optical switching substrate

preferably comprises $LiNbO_3$, and the element preferably comprises a transitional metal, such as titanium. Forming an alignment frame assembly includes etching openings in the first cladding layer down to the substrate. The openings preferably border on the first recess, and the alignment frame assembly includes a plurality of spaced corner assemblies. A plurality of optical output may be formed in the core layer such that optical signals are transferred directly from the microlenses to the optical output without blocking and in a criss-cross fashion.

Another embodiment of the present invention provides a method for producing an optical switching device comprising providing an unblocking optical switching substrate; diffusing an element into the optical switching substrate to produce a waveguide layer in the unblocking optical switching substrate; and disposing deflector electrodes on the unblocking optical switching substrate.

A further embodiment of the present invention provides a method for producing an optical switching apparatus comprising providing a substrate; disposing a first cladding layer on the substrate; disposing a core layer on the first cladding layer; forming microlenses in the core layer; forming an alignment frame assembly in the core layer; and engaging the alignment frame assembly with an optical switching device. For this embodiment of the invention, forming the optical switching device comprises providing an optical switching substrate; diffusing an element into the optical switching substrate to produce a waveguide layer in the optical switching substrate; disposing a plurality of first deflector electrode assemblies on the optical switching substrate; disposing a second cladding layer on the waveguide layer in the optical switching substrate; and disposing a plurality of second deflector electrode assemblies on the waveguide layer.

Additional embodiments of the present invention provide an optical substrate assembly and an optical switching apparatus. The optical substrate assembly includes a substrate; a first cladding layer disposed on the substrate; a plurality of deflector electrode assemblies supported by the first cladding layer; microlenses formed in the core layer; an alignment frame assembly formed in the core layer; and an optical switching device engaged to the alignment frame assembly. The optical switching apparatus comprises an optical switching substrate, which is preferably optically unblocking, including a waveguide layer produced by diffusing an element (e.g., a transitional element, such as titanium) into the optical switching device; and a plurality of second deflector electrode assemblies.

A method for transmitting a plurality of unblocked optical signals is also provided by embodiments of the present invention. The method for transmitting comprises the steps of:

a) forming an optical substrate assembly having an alignment frame assembly and a first core layer defining a plurality of microlenses and a second core layer spaced from and aligned with the first core layer and including a plurality of optical outputs;

b) forming an optical switching device possessing unblocking optical capabilities and having an optical waveguide layer;

c) engaging the alignment frame assembly with the optical switching device such that the optical waveguide layer is aligned with the first core layer and the second core layer; and

d) transmitting unblocked optical signals from the plurality of microlenses, through the optical switching device, and to the plurality of optical outputs.

These provisions together with the various ancillary provisions and features which will become apparent to those skilled in the art as the following description proceeds, are attained by the optical switching apparatus and method of the present invention, preferred embodiments thereof being shown with reference to the accompanying drawings, by way of example only, wherein:

<u>Brief Description of Drawings</u>

FIGS. 1(A) and I (B) illustrate top and side views of an integrated (2x2) cross-connect optical switch.

FIGS. 2 (A) - 2 (E) illustrate a process flow of a substrate on which the deflecting device is mounted.

FIGS. 3 (A) - 3 (F) illustrate a process flow of fabrication of the deflecting device.

FIG. 4 illustrates a schematic diagram showing an optical switch module.

FIGS. 5 and 6 illustrate the detailed structure of parts of the optical switch module.

FIGS. 7 (A) and 7 (B) illustrate a schematic diagram for showing deflection of light of a prism pair.

FIG. 8 shows a 2 by 2 channel optical switch module.

FIG. 9 illustrates a diagram for a light signal switching apparatus using the optical switch module.

Fig. 10 illustrates a schematic diagram of the light signal switching apparatus shown in Fig. 9.

FIGS. 11 (A) and 11 (B) show a structure of a light connector.

<u>Detailed Description of Preferred Embodiments of the Present Invention</u>

Referring in detail now to the drawings in combination with the detailed description hereinafter presented, there is illustrated and described an integration process, which allows fabrication of a non-blocking optical cross connect switching matrix with a large (e.g., at least up to 4000) number of I/O channels. The functional principle of the device is based on the EO induced deflection of the incoming optical beam or optical signal that can reroute the incoming light signal from an input port to an output port. Physical principle of the EO induced light beam deflection in piezoelectric materials is well known and is described in an article entitled "Low-Voltage Drive Electro-Optic Pb (Zr, Ti) 0_3 Waveguide Devices Fabricated By Solid-Phase Epitaxy" to Nashimoto et al of the Corporate Research Laboratories of Fuji Xerox Co., Ltd., Japan.

Embodiments of the present invention provide a hybrid integration process including an OE deflecting element disposed on a silicon substrate, allowing fabrication of a (2x2) cross-connect switching device. The (2x2) cross-connect switching device is used for illustration only, and embodiments of the integration process can easily be extended to fabricate switching systems with much larger number of I/O ports, such as 4000 x 4000 input/output ports. The silicon substrate is employed to exemplify the process. Therefore, the silicon substrate may be replaced by any other substrate, e.g., glass plate, printed circuit board, etc., which may be chosen according to the design requirements. The switching element or device in the present example is made from LiNb0_3 (lithium niobate, hereinafter termed as "LN") with a transitional metal (e.g., Ti) in-diffused waveguide and with top and bottom electrodes having a prism shape. It is to be understood that LN may be replaced by any material with a strong electro-optical coefficient. The material may be either a bulk or thin film material and the electrodes may be made in various shapes, such as prisms, gratings, various combinations and arrays of prisms and gratings, etc. Thus, LN means not only lithium niobate, but also other suitable electro-optic material to be formed as a wafer. Whole structures of an optical switching device and deflectors which implement the present invention are described in a Japanese patent application number Tokugan 2001040006, filed on February 16, 2001 and a Japanese patent application number Tokugan 2001-56009, filed on February 28, 2001. Waveguide circuits and/or optical signal routing and switching are described in the following U.S. Patents which are fully incorporated herein by reference thereto as if repeated verbatim immediately hereinafter: U.S. Patent No. 6,141,465 to Bischel et al.; U.S. Patent No. 5,572,540 to Cheng.; U.S. Patent No. 5,103,494 to Mozer; U.S.

Patent No. 5,894,538 to Presby; U.S. Patent No. 5,854,868 to Yoshimura et al.; U.S. Patent No. 5,465,860 to Fujimoto et al.; U.S. Patent No. 5,835,646 to Yoshimura et al.; U.S. Patent No. 5,540,346 to Fujimoto et al.; U.S. Patent No. 5,220,582 to Kaharu et al.; U.S. Patent No. 5,218,654 to Sauter; U.S. Patent No. 5,093,890 to Bregman et al.; U.S. Patent No. 5,822,475 to Hirota et al.; U.S. Patent No. 5,204,866 to Block et al.; U.S. Patent No. 5,010,505 to Falk et al.; U.S. Patent No. 4,850,044 to Block et al.; U.S. Patent No. 5,375,184 to Sullivan; U.S. Patent No. 5,757,989 to Yoshimura et al.; U.S. Patent No. 5,757,989 to Yoshimura et al.; U.S. Patent No. 5,541,039 to McFarland et al.; U.S. Patent No. 5,054,872 to Fan et al.; U.S. Patent No. 5,978,524 to Bischel et al.; U.S. Patent No. 5,732,177 to Deacon et al.; U.S. Patent No. 5,488,735 to Tanabe et al.; and U.S. Patent No. 5,408,568 to Hamilton et al.

Referring now to Fig. 4 there is seen a schematic diagram showing an optical switch module, generally illustrated as **100**. The optical switch module **100** is constructed by an input side optical waveguide portion **101**, an input side collimating portion **102**, an input side deflecting portion **103**, a common optical waveguide portion **104**, an output side deflecting portion **105**, a focusing portion **106**, and an outside optical waveguide portion **107**. The input side optical waveguide portion **101**, the input side collimating portion **102**, thus input side deflecting portion **103**, the common optical waveguide portion **104**, the output side deflecting portion **105**, the focusing portion **106**, and the outside optical waveguide portion **107** are all integrally formed on a substrate **98**. The input side optical waveguide **101** is constructed of a plurality of optical waveguides, so called cores, **101a-101a**, and clad layers **101b** which cover and are selectively disposed between the plurality of optical waveguides **101a-101a**, and keeps an optical beam lightwave within optical signal or respective optical waveguides **101a-101a** by using the difference of refractive index between the waveguide **l0la** and the clad layer **101b**. The output side of waveguide **107** is similar to the structure of the input side of waveguide **101** and is constructed of a plurality of optical waveguides, so called cores, **107a-107a**, and clad layers **107b** which cover and are selectively disposed between the plurality of optical waveguides **107a-107a**, and keeps an optical beam, or optical signal, or light wave within respective optical waveguides **107a-107a** by using the difference of refractive index between respective waveguides **107a** and respective clad layers **107b**.

As shown in Fig. 4, the number of the optical waveguides **101a** of the input side of optical waveguide **101** is equal to the number of the optical waveguides **107a** of the output side of optical waveguide **107**. Herein after, the number of the optical waveguides **101a** and the

number of the optical waveguides **107a** are referred as "n". Here, "n" is an integer having a value of two or more. In another embodiment of the invention, and by way of example only, it is to be understood that the number of the optical waveguides **101a** of the input side of optical waveguide **101** may be different from the number of the optical waveguide **107a** of the output side of optical waveguide **107**.

The collimating portion **102** is comprised of "n" number of microlenses or collimating lenses **102a**. Each of the collimating lenses **102a** is located at a position slightly apart from the end portion of respective optical waveguides **101a**. The light output from optical waveguides **101a** is initially broadened out or scattered out in a radical manner, but then it becomes a collimatingd confined, or registered light in the collimating lens **102a**.

In the input side deflection portion **103**, "n" number of light deflection elements **103a** is provided. Each of the light deflection elements **103a** is positioned at a location slightly apart in a light axis direction from respective collimating lens **102a**. The light deflection element **103a** deflects or changes the propagation direction of light signal by using Pockels cell effect, namely an electro-optic effect.

The common optical waveguide **104** is constructed by a slab type waveguide. The common optical waveguide **104** transmits a light that passed through the input side light deflection portion **103** to the output side light deflection portion **105**. Within the common waveguide **104**, plural optical signals pass through at the same time. Since these optical signals straightforwardly move in a predetermined direction within the common waveguide **104**, the plural optical signals are transmitted without interfering or distorting each other. In other words, there is no criss-crossing of optical signals.

At the output side light deflection element portion **105**, "n" number of light deflection elements **105a-105a** are provided. These light deflection elements **105a-105a** deflect, change, or alter an optical beam, optical signal, or a light wave that the light deflection elements **105a** receive after passing through the common optical wave guide **104**. Light deflection elements **105a**, respectively, change direction of respective optical beams to a direction parallel to the optical axis direction of corresponding respective optical waveguides **107a**. In a preferred embodiment of the direction, both light deflection elements **103a** and **105a** have generally the same structure.

The focusing portion **106** is comprised of "n" number of focusing lenses **106a-106a**. These focusing lenses **106a-106a** function to guide a light signal that passes through the

respective light deflection element **105a** to the optical waveguide **107a** by focusing the light signal.

The waveguides or cores may be manufactured of any suitable material. For example, the waveguides may be formed using a highly transparent, highly heat-resistant polymer such as a fluorinated polyimide, or quartz or another glass or polymer material. The same type of material may also be used for the cladding layers, or an organic and/or inorganic hybrid may be used. The film forming method for these polymer systems may be spin coating, dip coating, spray coating, or a vapor phase growth process such as evaporation polymerization or CVD. For glass systems, sputtering, evaporation, CVD, ion plating or the like may be employed, and when a sol-gel method is used, spin coating, dip coating or spray coating may be employed.

Referring now to Figs. 5 and 6, there is seen the detailed structure of parts of the optical switch module **100**. The details of the collimating lens portion **102**, the input side light deflection element portion **103**, the output side light deflection element portion **105**, and the focusing portion **106** in the optical switch module are explained with reference to Figures 5 and 6.

The collimating lenses **102a-102a**, which are constructed of the same material as the collimating portion **102**, as shown in Figs. 5 and 6, are preferably a two-dimensional lens comprised of two portions **102c** and **102d**, each portion having a different refractive rate or index from each the other. The portion **102c**, having a high refractive rate (a convex lens portion), is preferably formed by the same material used for forming the optical waveguides **101a** and **107a**, so-called core. The portions **106d** and **102d**, having a low refractive rate, are preferably an opening, air, or any suitable index matching material (e.g., gels) having a refractive index lower than the refractive index of the core (e.g., portions **102c** and **106c**).

The focusing lenses **106a-106a** of the focusing portion **106** are similar to the collimating lens **102a**. Each focusing lenses **106a** includes a portion (a convex lens portion) **106c** having a high refractive rate and the portion **106d** having a low refractive rate. Preferably, the refractive direction of focusing lenses **106a-106a** is opposite to the refractive direction of collimating lenses **102a-102a**.

The light deflection elements **103a-103a**, constructed as part of the input side light deflection portion **103**, comprise one or more prism pairs **103p-103p**. One prism pair **103p**, as shown in Fig. 6, includes a slab type waveguide **103b** made from a material having electro-optic effects. As further best shown in Fig. 6, the first and second upper electrodes **103c** and **103d** are

formed on the upper side of slab type waveguide **103b**, and first and second lower electrodes **103e** and **103f** are formed on the lower side of slab type waveguide **103b**. The first and second upper electrodes **103c** and **103d** and these first and second lower electrodes **103e** and **103f** are formed in a shape of a triangle (a wedge shape), respectively.

The first upper electrode **103c** and the first lower electrode **103e** are opposed and face each other while holding the slab type waveguide **103b** therebetween. The first upper electrode **103c** and the second upper electrode **103d** are spaced and face each other along an oblique side associated with each of the upper electrodes **103c** and **103d**. The second upper electrode **103d** and the second lower electrode **103e** are also opposed and face each other while holding the slab type waveguide **103b** therebetween. Thus, the slab type waveguide **103b** is common for each prism pair **103p**. By using such a structure for each prism pair **103p**, the size of each prism pair may be smaller.

Continuing to refer to Fig. 5, the light deflection elements **105a-105a** of the output side light deflection portion **105** are similar to the input side light deflection elements **103a-103a**, and include the slab type waveguide **105b** made from a material having the characteristic of electro-optic effects, and one or more prism pairs **105p-105p**. Each of the prism pairs **105p** is identical to each of the prism pairs **103p**, and more specifically includes a pair of first electrodes (not shown), but which correspond to and are essentially identical to the first upper electrode **103c** and the first lower electrode **103e** respectively, and a pair of second electrodes (not shown), but which correspond to and are essentially identical to the second upper electrode **103d** and the second lower electrode **103f**, respectively. Since they are identical to the electrodes for prism pair **103p**, the first and second upper electrodes and the first and second lower electrodes for the prism pair **105p** are formed into a shape of a triangle (a wedge shape), respectively.

Referring now to Figs. 7 (A) and 7 (B) a schematic diagram is seen for illustrating deflection of light of prism pair **103p** (i.e., electrodes **103c** and **103e** and electrodes **103d** and **103f**). In Fig. 7, arrow **A** indicates a direction of an axis of crystallization of the slab type waveguide **103b** and arrow **E** indicates a direction of electronic field applied to the prism pair **103p**.

As shown in Fig. 7 (A), the first lower electrode **103e** is connected to the ground line (G). In this state, when a control voltage (+V) is applied to the first upper electrode **103c**, the refractive rate of the slab type waveguide **103b** between the first upper electrode **103c** and the first lower electrode **103e** changes from n to n + Δn. Thus, the transmission direction **A** of light

signal is deflected to left-hand side direction in view of the moving direction of the light signal at an angle θ. On the other hand, in a state that the second upper electrode **103d** is connected to the ground line (G) as shown in Fig. 7 (B), where a control voltage (+V) is applied to the second lower electrode **103f**, the refractive rate of the slab type waveguide **103b** located between the upper electrode **103d** and the lower electrode **103f** changes from n to n - Δn. Thus, the transmission direction **A** of light signal is further deflected to the left-hand side direction in view of the transmitted direction of the light signal at an angle θ. Hereinafter, these electrodes to which the control voltage is applied may also be called control electrodes, which correspond to the first upper electrode **103c** and the second lower electrode **103f**.

Therefore, a light signal can be deflected at an angle 2θ with one prism pair. Obviously, where "m" number of prism pairs **103p** are located in tandem in each of the channels with "m" being an integer having a value of two or more, the deflection direction from the transmission direction of the light signal can be 2θ x m. The electrodes pinching the slab type waveguide made by a material with the characteristic of electro-optic effect between the electrodes may be formed to directly contact with the slab type waveguide (a core layer). In this modification, a clad layer inserted between these electrodes and the slab type waveguide (a core layer) avoids the loss of light due to the transmission from a metallic boundary surface.

Referring now to Fig. 8, there is seen a 2x2 channel optical switch module **100a**. The optical switch module **100a** transmits the first light signal input into the first input port **1** to either output port **1** or to the output port **2**. The second light signal input into the first input port **2** is transmitted to the remaining output port not receiving the first light signal, which is output port **1** or output port **2**. Thus, if output port **2** receives the first light signal from input port **1**, output port **1** would receive the second light signal from input port **2**. When there is no criss-crossing of optical signals, such as where a light signal input into the first input port **1** is transmitted to the output port **1**, and a light signal input into the second input port **2** is transmitted to the output port **2**, a control voltage is not applied to any of the light deflection elements **113a, 113b, 115a**, and **115b**, and thus, no light signals are deflected at the light deflection elements **113a**, **113b, l15a**, and **115b**. Accordingly, the light signal input into channel waveguide **111a** would be transmitted to light waveguide **117a**, and the light signal input into channel waveguide **111b** would be transmitted to light waveguide **117b**, all without any optical criss-crossing due to any applied control voltage.

Where a light signal input into the first input port **1** is to be transmitted to the output port **2** and a light signal input into the second input port **2** is to be transmitted to the output port **1**, a plus control voltage +V would be applied to the control electrodes of the light deflection elements **113a** and **115b** and a minus control voltage -V would be applied to the control electrodes of the light deflection elements **113b** and **115a**. Accordingly, the light signal input into the input port **1** would be deflected toward the right hand direction in view of the transmission direction of the light signal at the light deflection element **113a**, and then, upon reaching light deflection element **115b**, the deflected light signal would be deflected again into a direction parallel to the longitudinal axis of optical waveguide **117b** at light deflection element **115b**, and would be focused by focusing lens **116b** into the optical waveguide **117b**, and then transmitted into the output port **2**. Similarly, the light signal input into the input port **2** would be deflected in a left hand direction in view of the transmission direction of the light signal at the light deflection element **113b** and into light deflection element **115a**, and then, upon reaching light deflection element **115a**, the deflected light signal would be deflected again into a direction parallel to the longitudinal axis of optical waveguide **117a** at the light defection element **115a**, and would then be transmitted to the output port **1** through the focusing lens **116a** and the optical waveguide **117a**.

Referring now to Fig. 9, a diagram is seen for a light signal switching apparatus **150** using the optical switch module **100** as described previously. Fig. 10 shows a schematic diagram of the light signal switching apparatus shown in Fig. 9. The light signal switching apparatus **150** has 64 inputs of WDM signal in which light signals for 64 wavelengths with 40Gb/s are multiplexed. The transmittal direction of these multiplexed light signals are switched or changed in the light signal switching apparatus **150**.

The light signal switching apparatus **150** comprises sixty four AWG light dividers **131** arranged along in a vertical direction in Fig. 9, a three step-structure light switch module **130**, sixty four light composers **133**, and sixty four light amplifiers (EDFA: Erbium Doped Fiber Amplifier) **134**. In each step of the three step-structure light switch module **130**, there are a plurality of light switch modules, such as optical switch module **100**. More specifically, each step of the three step-structure light switch module **130** includes the plural light switch modules **132a**, **132b**, and **132c**. Each of the plural light switch modules **132a**, **132b**, and **132c** is constructed from sixty-four light switch modules, each having 64 x 64 channels. More specifically further, each of the sixty-four light switch modules includes sixty-four light input

ports and sixty-four light output ports. Each of the sixty-four light switch modules are different from the Fig. 8 light switch module **100a** which has two by two channels because of the number of the input ports and the number of the output ports. In the first step, the sixty-four switch modules **132a1-132a64** are arranged in a direction with the substrate of the light switch module **132a**. As similar to the first step, in each second step and each third step, the sixty-four switch modules are arranged in an appropriate registry direction with the substrate of the respective light switch modules **132b** and **132c**. In the second step of the three step-structure light switch module **130**, the sixty-four light switch modules **132b1-132b64** are located in a state or position where they are rotatably disposed at 90 degrees against and with respect to the sixty-four light switch modules **132a** in the first step and the sixty-four light switch modules **132c** in the third step. The sixty-four light switch module **132c** in the third step is located around an axis extending along one of the channels of the light switch module **100a**.

Each of the light dividers **131** and each of the light switch modules **132a** in the first step are coupled by a light connector **135a**. Likewise, each of the light switch modules **132a** in the first step and each of light switch modules **132b** in the second step are coupled by a light connector **136a**. Similarly, each of the light switch modules **132b** and each of the light switch module **132c** are coupled by a light connector **136b,** and each of the light switch modules **132c** and each of the light composers **133** are coupled by a light connector **135b**.

Figs. 11 (A) and (B) show a structure of the light connector **136**. Fig. 11 (A) shows a top plan view of the light connector **136**, and Fig. 11 (A) shows a vertical sectional view taken along the plane of the B-B line in Fig. 11 (A). As shown in Figs. 11 (A) and (B), the light connector **136** comprises a substrate **140** having various number of tiny lenses **141** through which a light signal passes in the direction of the thickness (i.e., a vertical direction) of the substrate **140**. With the light connector **136**, the lenses **141** are arranged along two-dimensional directions. But with the light connector **135**, lenses **141** are arranged along only a single dimensional direction. The arrangement pitch of the lenses **141** is set to the same as the interval pitch of the input ports and/or output ports of the light switching modules **132a**, **132b**, and **132c**. The lenses **141** of these light connectors **135** and **136** focus a light output from a preceding optical device and transmit same to an immediate subsequent optical device thereof; thus, they are useful to lower the loss of transmission. In this embodiment of the optical switching device, there is a microprocessor controller for turning on and/off the voltage applied to each of the control electrodes of the light deflection elements in each of light switching modules **132a**, **132b**, and

132c. The microprocessor (not shown in the drawings) is coupled to each of the electrodes of the light deflection elements through a conductive wire which transmits an electronic signal from and controlled by the microprocessor.

Figs. 1 (A) and (B) show top and side views of the schematic structure of an integrated (2x2) switching device **8**. The switching part of the device **10** includes a LN block **12**. The LN block **12** is prepared from a single crystal LN wafer in a manner described below. A two-dimensional transitional metal-diffused (e.g.,Ti-diffused) waveguide (WG) **14** is formed in the LN block **12** for vertical confinement of the transmitting light modes. The thickness of the LN block **12** may be varied from 10 to 500 μm. In Figs. 1(A) and 1(B), the LN block **12** is placed with Ti-diffused waveguide **14** facing a silicon substrate **10**, in order to align a polymer waveguide core **40** with a LN slab waveguide core **14**, which is the two-dimensional Ti-diffused waveguide. The waveguide **14** functions as the previously described common waveguide.

In the case of very thin LN films, a structural embodiment is possible in which the bottom layer (i.e., a low clad polymer layer **32**) is etched all the way down to the substrate **30** in order to form a recess **91** (see Fig. 2E), and the LN block **12** is placed in the recess **91** such that the waveguide region **14** (the two-dimensional Ti-diffused waveguide **14**) is generally aligned with waveguide layers (identified as "**38c**" and "**40**" below) and the bottom surface of the two-dimensional Ti-diffused waveguide **14** is located equal to or slightly lower than the top surface of the low clad polymer layer **32**. In another structural embodiment, the thickness of LN block **12**, not including the thickness of the two-dimensional Ti-diffused waveguide **14**, is the same as, or slightly wider than, or similar to the thickness of the polymer bottom cladding layer **32** and to the thickness of the core layer **40**.

Therefore, and recapitulating, the LN block **12** may be placed with Ti-diffused waveguide facing the substrate **30** in order to level the polymer waveguide core (i.e., low clad polymer layer **32**) with the LN slab waveguide core (i.e., Ti-diffused waveguide **14**). In the case of very thin LN films, the bottom layer of the polymer waveguide core may be etched all the way down to the silicon substrate **30**, and the LN block **12** may be placed with the waveguiding region up, assuming that the thickness of the LN is similar to the thickness of the polymer bottom cladding and the core.

Optical fibers, not shown in Figs. 1 (A) and (B), transmitting the light signals are coupled, at the right hand side of the device **8**, to a channel waveguide formed from an optical polymer material, well known to those skilled in the art. The respective optical fibers are

arranged such that the input end of the respective optical fibers is faced with the output end of the respective cores **107a** of the output end of the optical waveguide **107**. There are standard techniques which may be used for fiber placement on the silicon substrate **30**. As an example, optical fibers can be attached using V-grooves formed on the silicon substrate **30**, or any other technique known to those skilled in the art. In cases of substrates other than silicon substrate, fiber placement can be performed by other methods well known to those skilled in the art.

The channel waveguide is terminated with waveguides **101a1** and **101a2**, as best shown at the left side of Fig. 1. The waveguides **101a1** and **101a2**, as well as micro lenses **102a1** and **102a2**, are formed from the same material used for the optical polymer core layer **40**. The micro lenses **102a1** and **102a2** focus the diverging light beam coming out of the waveguides **101a1** and **101a2** into an in-plane parallel beam, which will propagate through the device **8**. Since the propagating light modes are confined vertically in both polymer lens **102a1** (or **102a2**) and the LN slab waveguide **14**, there is no need for vertical focusing of the beam. Changing the lens radius of curvature enables variation of the focal length of the micro lenses **102a1** and **102a2**. The focal length of the micro lenses **102a1** and **102a2** should be adjusted to compensate the beam divergence as it comes out of a part of the channel waveguides.

The channel waveguides preferably comprise three layers of an optical polymer material. More specifically the channel waveguides include a waveguide and micro-lens combination and an output waveguide. The low clad polymer layer **32** and the LN block **12** also are part of the channel waveguides. The first layer of the channel waveguides at the waveguide and micro-lenses combination is a lower cladding layer **38a** with a lower refractive index.

The second layer of the waveguide and micro-lenses combination is the waveguide core with a refractive index higher than that of the lower cladding layer **38a**. The second layer **38c** of the waveguide and micro-lenses combination includes the waveguides **101a1** and **101a2** and the micro lenses **102a1** and **102a2** as the collimating lenses. Furthermore, the second layer **38c** includes the clad layer **101b**, the convex lens portion **102c** having a high refractive index, and the portion **102d** having a low refractive index as shown in Fig. 5.

The third layer of the waveguide and micro-lenses combination is an upper cladding layer **38b** with a refractive index lower than that of the second layer **38c**, which may be called a core layer and may be the same as or similar to the first layer **38a**. In the structure shown in Fig. 1, the third layer **38b** is disposed onto the second layer **38c**. The lower and upper cladding layers

38a and **38b** may be formed from the same polymer material with an identical refractive index. However, the refractive indexes may be different.

As similar to the waveguide and micro-lenses combination, the first layer of the output waveguide is a lower clad polymer layer **42a**, and the second layer thereof is a polymer core layer **40**, and the third layer thereof is an upper clad polymer layer **42b**. The lower and upper clad layers **42a** and **42b** are formed from the same polymer material with an identical reflective index that is lower than that of the core layer **40**. The second layer of the output waveguide includes focusing lenses **106a** and **106a**, each constructed from the convex lens portion **106c**, the low refractive index portion **106d**, the optical waveguides **107a** and **107a**, and the clad layer **107b** (all as best shown in Fig. 5).

The lower cladding layers **38a**, **32**, and **42a** are preferably polyimide layers and are deposited directly on the silicon substrate. The LN deflector block **12** is placed over the low cladding polymer layer **32** with the slab waveguide **14** at the bottom of the LN block **12**. In this case the LN slab waveguide **14** is self-aligned with the core of the micro-lenses **102a1** and **102a2**, namely the second layer **38c**, and the core layer **40**.

Bottom electrodes **34a1**, **34a2**, **36b1**, and **36b2** for the deflectors **103a1**, **103a2**, **105a1**, and **105a2**, as well as the corresponding wirings for the bottom electrodes **34a1**, **34a2**, **36b1**, and **36b2**, are made and placed over the first polymer layer **32** in accordance with procedures well known in the art. The bottom electrodes **34a1**, **34a2**, **36b1**, and **36b2** are preferably covered with a thin protective layer **36**. The thin protective layer **36** is preferably a sputtered layer of SiO_2, or a similar dielectric material deposited by any suitable means. Each of the bottom electrodes **34a1**, **34a2**, **36b1**, and **36b2** is connected to the bottom contact pads **84a1**, **84a2**, **84b1**, and **84b2**. Each of the bottom electrodes **34a1**, **34a2**, **36bl**, and **36b2** works as the first and second lower electrodes of the prism pairs **103p** and **105p**, so the shape of the bottom electrodes **34a1**, **34a2**, and **36b2** is preferably a triangle (a wedge shape) respectively, as shown in Figs. 5 and 6. In Figs. 1-3, four bottom electrodes are depicted and numbered, with the number of the bottom electrodes are to be matched correspondingly with the number of the top electrodes.

The bottom electrodes **34al**, **34a2**, **36b1**, and **36b2** may be deposited directly under the two-dimensional Ti-diffused waveguide **14** of the LN block **12**. In this alternative structural embodiment, the bottom electrodes **34a1**, **34a2**, **36b1**, and **36b2** are then connected, e.g. with

solder bumps, to the wiring for the bottom electrodes **34a1**, **34a2**, **36b1**, and **36b2** formed on the bottom polymer layer **32**.

Top electrodes **18a1**, **18a2**, **18b1**, and **18b2**, and the contact pads **16a1**, **16a2**, **16b1**, and **16b2** connected to the top electrodes **18a1**, **18a2**, **18b1**, and **18b2** are deposited on the LN block **12** in accordance with procedures well known in the art. The contact pads **16a1**, **16a2**, **16b1**, and **16b2** are connected to the deflector electrodes **18a1**, **18a2**, **l8b1**, and **18b2** of the deflecting elements **103a1, 103a2, 105al**, and **105a2**. In Figs. 1-3, the contact pads **16a1, 16a2, 16b1**, and **16b2** respectively connect to a top electrode of one of the deflectors within the respective deflecting elements **103a1**, **103a2**, **105a1**, and **105a2**. More specifically, contact pads **16a1**, **16a2**, **16b1**, and **16b2** respectively electrically, conductively couple to all of the top electrodes of the deflectors within the respective deflecting elements **103a1**, **103a2**, **105a1**, and **105a2** in an actual switching apparatus since the optical switching apparatus has only two channels, namely two input/output ports. Thus, the number of the contact pad increases dependent upon the increase of the number of the channels; namely it increases proportionally to the increase of the number of the input/output ports. In this situation, the contacts pads are separately formed such that the contacts pads are not electrically conductive with each other.

As similar to the bottom electrodes, each of the top electrodes **18a1, 18a2, 18b1**, and **18b2** works as the first and second top electrodes of the prism pairs **103p** and **105p**. The shape of the top electrodes **18a1**, **18a2**, **18b1**, and **18b2** is preferably a triangle (a wedge shape) respectively, as shown in Figs. 5 and 6. In Fig. 1, three pairs of the prism pair are provided for each deflecting elements. Thus, the number of top electrodes should be six for each of the deflecting elements. In light of the number of top electrodes, the number of bottom electrodes of each deflecting elements should also be six.

The contact pads **16a1**, **16a2**, **16b1**, and **16b2** are connected to microprocessors for controlling the switching, which are mounted in a housing in which the optical switching modules are also located. The control signal lines extended from the microprocessors increase in proportion to the increase of the number of the channels; namely the number of the input/output ports of the optical switching apparatus with optical switching modules.

All of the bottom contact pads **84a1**, **84a2**, **84b1**, and **84b2** are connected to the common ground line (G) not shown in Figs. 1-3. All of the deflectors used in Fig. 1 of each deflecting elements **103a1**, **103a2**, **105a1**, and **105a2** have the same structure of the deflecting elements shown in Figs. 5-7.

Alignment frames **44a**, **44b**, **46a**, and **46b** are formed in the lower cladding and core polymer layers **38a, 38c, 42a**, and **40** with the same mask used for patterning of the channel waveguides and micro-lenses. The purpose of the alignment frames **44a, 44b, 46a**, and **46b** is engaging, positioning and alignment of the LN block **12** on the substrate **30**. The output two-dimensional slab waveguide formed from three optical polymer layers **42a**, **40**, and **42b** couples the light beam outgoing from the LN block **12** with the output fiber for further signal transmission.

The bottom and top electrodes **34a1, 34a2, 36b1, 36b2, 18a1, 18a2, 18b1**, and **18b2** are mutually aligned to be on top of each other, as similar to the arrangement shown in Figs. 5-7. The shapes of the electrodes define the active deflecting elements of a desired design. However, it should be noted that in the case of a relatively thin (about 5-25 μm) deflector, i.e., the height of the deflector block or active deflecting film deposited on a block from an electrically conductive material is small, one of the electrodes (i.e., either the top or the bottom one) can be made from a blanket conductive film, because fringing effects are minimized for thinner films.

In order to apply a control voltage to the top electrodes **18a1, 18a2, 18b1**, and **18b2** as previously explained with reference to Figs 5-7, the contact pads **16a1, 16a2, 16b1**, and **16b2** are formed on the top outside surface of the LN block **12**. In order to connect the bottom electrodes **34a1, 34a2, 36b1**, and **36b2** with the ground line (G), the contact pads **84a1**, **84a2**, **84b1**, and **84b2** are formed in the area of the top surface of the silicon substrate **30** where the LN block **12** is not placed and is open for further wiring connections to the ground line (G).

Switching of modes from one input channel into one of the output channels is realized by applying voltage to the opposite electrodes, as previously described in reference to Figs. 5-7. Without applied voltage to any of the top electrodes, the optical signal goes straight through the two dimensional Ti-diffused waveguide **14** without being deflected. The applied voltage changes the refractive index of LN (or any other electro-optic material which is used) between the top and bottom electrodes, which results in deflection of the light beam from its initial path. When the plus voltage is applied to the top electrodes of the deflecting elements **103a1** and the top electrodes of the deflecting elements **105a2**, the optical signal is deflected from the deflecting elements **103a1** of the first channel to the deflecting elements **105a2** of the second channel, and also the optical signal that reaches the deflecting elements **105a2** is deflected to the second output port of the output waveguide.

In this manner the crossbar operation can be achieved. Although the switching device depicted in Fig. 1 has only two input channels and two output channels, there are three prism deflectors shown for each input port and there are three prism deflectors for each output port. For (2x2) configuration only one deflector per port on each of the input side and the output side is required to switch the signal between two I/O ports. More deflectors were added in Fig. 1 to show that the integrated switching device structure can be easily extended to any number of I/O ports.

The fabrication process of the optical switching device is explained with reference to Figs. 2-3. The fabrication process for the switching device shown in Fig. 1 comprises the following three levels: (a) fabrication of the substrate with channel waveguides, micro lenses, bottom electrodes and electrical wiring (level 1); (b) fabrication of the beam deflector from a single crystal LN block, or any other type of bulk or thin film electro-optic material (level 2); and (c) assembly of the deflector block on the substrate (level 3).

Level 1: Preparation of the Substrate with Channel Waveguides, Micro Lenses, Bottom Electrodes and Electrical Wiring

Fig. 2 shows a schematic process flow for fabrication of the substrate on which the deflecting device is mounted. As shown in Fig. 2 (A), a silicon wafer **400** is provided for use as a substrate. The silicon wafer **400** may be with or may not be with a thin silicon dioxide layer terminating on the surface of the substrate. Then, a low cladding layer (PL 1) **410** is deposited on the silicon wafer **400**. To form the low cladding layer **410**, low cladding optical polymer material is preferably spin coated on the silicon wafer **400**. The thickness of the low cladding layer **410** may vary from 1 to 30 μm depending on the waveguide design. The preferable thickness of the low cladding layer **410** for one embodiment would be in the range 5-15 μm.

As shown in Fig. 2 (B), recess formation process is performed. A recess **420** is formed on the top surface of the spin coated low cladding layer **410**. In this process, the silicon wafer **400** is first coated with photoresist (PR, not shown in Fig. 2) and is patterned with photolithography. An etching process, e.g., O_2 plasma-etching process is applied to form the recess **420** through the opening in the masking photoresist layer. This step is for vertical leveling of the polymer waveguide cores **38c** and **40** and the LN slab waveguide core **14**. This step is optional and can be skipped if a slight misalignment is not critical for the mode coupling at the waveguide/deflector block interface.

In Fig. 2 (C), the bottom electrodes **34a1**, **34a2**, **36b1**, and **36b2** and the contact pads **84a1**, **84a2**, **84b1**, and **84b2** with the wiring, not shown in Fig. 1, are formed on the bottom surface in the recess **420**. Metal layer(s) are deposited on the bottom cladding surface **410** to form bottom electrodes, contact pads, and the wiring. The deposition of the metal layers may be by sputtering or plating or any other suitable way. Any electrically conductive material can be used as the bottom electrodes, the contacts pads, and the wiring. Main restrictions for the material to be used as the metal layers are compatibility with the underlying polymer layer and the material etching possibilities. Furthermore, the bottom electrodes can be deposited directly on the under surface of the LN block **12** in the integration level 2 as will be explained later. In this process, the photoresist is applied over the low cladding layer **410** and patterned with photolithographically. The metal pattern for the metal layers is formed through the mask by either wet or dry etch. A lift-off process, well known to those skilled in the art, may also be used to form the metal pattern.

As shown in Fig. 2 (C), deposition of the bottom electrode (BE) protection layer **18** is done. This is an arbitrary step and may not be necessary if there is no need to protect the BE. The protection layer **18** protects the bottom electrodes **34a1**, **34a2**, **34b1**, and **34b2** from corrosion and shorting during the operation at higher voltages. The protection layer **18** is formed by using sputtering technology. The protection layer **18** is made of SiO_2 or any other appropriate dielectric material. It is a thin SiO_2 layer; preferably having a thickness ranging from about 0.1 to about 5.0 μm.

The BE protection layer **18** has a pattern matching the shape of the LN block **12**. The process of forming the protection layer **18** includes, as similar to the other process, deposition of photoresist layer onto the low cladding layer to cover the bottom electrodes, and photolithography. For instance, the SiO_2 protection layer **18** may be dry etched in CF_4/H_2 plasma or any appropriate wet or dry etching method. Addition of the reducing agent H_2 in the CF_4 plasma allows increase of the etch selectivity between silica and the polymer of the low cladding layer **410**.

As shown in Fig. 2 (D), the next step is a spin coating deposition of the core polymer layer **430** having a higher refractive index than that of the bottom-cladding layer **410**. The thickness of the core polymer layer **430** can be varied according the design rules from about 1 μm to about 30 μm. The preferable thickness range for the core polymer layer is about 3-10 μm.

As shown in Fig. 2 (E), the core and bottom cladding layers **410** and **430** are patterned through photolithography with a single mask using for example O_2 plasma etch. The channel waveguide core **38c** including the micro lenses **102a1** and **102a2**, the alignment frame **44a, 44b, 46a**, and **46b**, and the output waveguide core **40** are formed in the two polymer layers **410** and **430**.

The upper cladding layers **38b** and **42b** possessing a low refractive index material are deposited and patterned in the same manner as the lower cladding and core layers so as to open the front side of the micro-lenses and the output slab-waveguide. The top plane view of the polymer waveguide and micro-lenses is similar to the top plane view of the output waveguide as shown on the right side of Fig. 1 (A). If required, grooves or trenches for placing optical fibers may be formed on the substrate **400** at the left side of the polymer waveguides and micro-lenses, and at the right side of the output waveguide for fiber placement.

<u>Level 2: Preparation of the LN Block for the Light-Deflecting Device</u>

Fig. 3 shows a process flow of fabrication of the deflecting device. As mentioned above, this is an example of a deflector block fabrication and it is not restricted to LN. Any other bulk or thin film material with OE properties may be used.

In Fig. 3 (A) and (B), in order to fabricate the LN deflecting device in this example, a 100 or 75 mm z-cut LN wafer **500** is prepared. The thickness of the wafer **500** maybe either about 1 or about 0.5 mm depending on the handling and polishing convenience of the wafer **500**. Such LN wafer (LNO crystals) is available from Crystal Technologies, Inc.

Using the LN wafer **500** rather than sputtering it onto a substrate is cost effective. The thickness of the common waveguide **104** and the slab type waveguide **103b** required in the optical switching apparatus is relatively high. The two dimensional (2D) waveguides **14** are formed on top of the LN wafer **500** by titanium indiffusion. The processing conditions such as Ti-layer thickness, annealing time and temperature can be adjusted according to the required waveguide design that depends on the wavelength of the light used. In a preferred embodiment, Ti-layer **510** of 700 Å thickness is blank sputtered on the -Z surface of the LN wafer **500**, as shown in Fig. 3 (A). Then, Ti indiffusion is performed in an annealing furnace at a temperature of 1050°C for 8 hours, as shown in Fig. 3 (B). The resulting Ti-diffused waveguide **520** was simulated to support only single mode propagation for a 1.3-1.5 μm light. The insertion losses are expected to be less than 0.5 dB/cm.

In the next step as shown in Fig. 3 (C), a thin SiO_2 film **530** is deposited on the surface of the LN wafer **500**. The thickness of the thin SiO_2 film **530** is 0.1-1 μm. It may be less than 0.1 μm. The thin film layer **530** serves as an isolation of the Ti-diffused waveguide **14** from the prism electrodes **34a1**, **34a2**, **34b1**, and **34b2**, and also as the upper cladding layer for the LN slab waveguide **14**.

As shown in Fig. 3 (C), the LN wafer **500** is then diced into blocks which are going to be used as active elements in deflecting devices. In the dice or cleave step, the silicon substrate **30** is severed to many pieces of the desired device shape. The dicing or cleaving procedure may also be applied at any earlier stage of the processing, depending on the general requirements. Obviously, the outside dimension of the LN block separated matches with the open space formed by the alignment blocks **44a, 44b, 46a**, and **46b** with manufacturing allowances.

As shown in Fig. 3 (D), the front and rear sidewalls of the severed LN block **540** are polished with an optical quality for coupling of incoming and outgoing light modes.
In the next step shown in Fig. 3 (E), the LN block **540** may be thinned by backside lapping and polishing. The block thickness may be in the range 10-500 μm. Since LN is a very brittle material, the limitation on the block thickness are imposed from handling and processing difficulties.

After the blocks are thinned, as shown in Fig. 3 (F), a metal film **550** is sputtered on the surface of the LN block **540** for making the top electrodes, the contact pads, and the wiring for the top electrodes and the contact pads.

Fig. 3 (F) shows a side view of the final form of the LN block **540** with the Ti indiffused slab waveguide **520** and the metal layer **550** for the top electrodes, etc. After forming the metal layer **550** by sputtering on the backside (in Fig. 3 (F) it is the topside) of the LN block **540**, a photoresist layer is rolled on the topside of the LN block **540**. Then, lithography is performed and the metal layer is etched to form the top electrodes on the LN block **540**.

Level 3: Assembly of the Deflector Block on the Substrate

The LN block **540** is inserted into the alignment frame **44a, 44b, 46a**, and **46b** formed in the polymer layers **410** and **430**. The placement of the block **540** may be realized by the flip-chip bonding technique. The LN block **540** is attached to the substrate made through the process shown in Fig. 2 with an adhesive material and leveled and registered in order to adjust the

polymer and LN waveguides. The adhesive material is, e.g., an epoxy material. It is coated to the under surface of the LN block **540**, preferably the surface of thin SiO_2 film layer **530.**

By the practice of the present invention there is provided a hybrid integration on a single substrate of the switching matrix and two-dimensional micro-optics. The switching matrix is fabricated from a single block electro-optic material which incorporates cascaded light beam deflecting elements for the input channels, slab waveguide for non-blocking transmission of the signal between the input/output deflectors, and output deflecting elements to couple the rerouted signals into the output waveguides. Two-dimensional micro-optics made from optical polymer layers for coupling of the input and output fibers in and out of the switching matrix. The principles of the present invention are based on electro-optic switching principle; i.e., there is high potential for very fast switching (~40 Gb/s and higher). A 2x2 switch fabricated with the technique of embodiments of the present invention was measured to have a switching speed of less than about 50 microseconds. There are no movable switching parts; thus, the present invention is highly durable and reliable. There are no heating electrodes, thus there are no thermal management problems. The present invention has a high compatibility with existing semiconductor processing techniques and equipment, and the switching matrix on a single block allows low cost fabrication of deflectors for a large number of I/O channels. Several switching devices may be fabricated on a single wafer, and thus, there would be a high yield at a lower cost.

It is to be understood that this invention is not limited to those embodiments and modifications described in the specification. Modifications and variations can be made one skilled in the art without departing from the sprit and scope of the invention. Moreover, any one or more features of any embodiment of the invention may be combined with any one or more other features of any other embodiment of the invention, without departing from the scope of the invention.